Summary of the Mars Relay Network
and related topics

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11 Dec 2019

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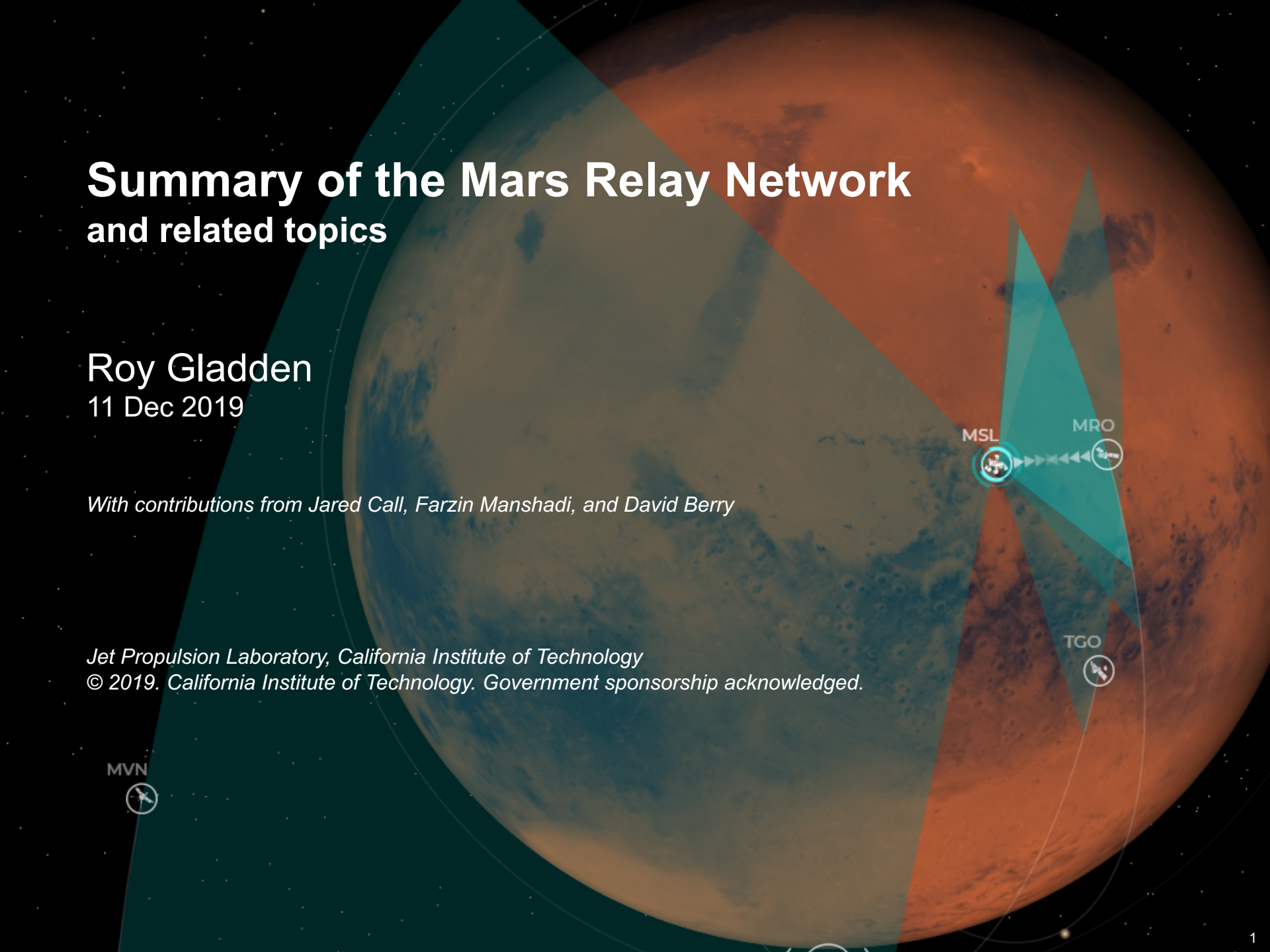
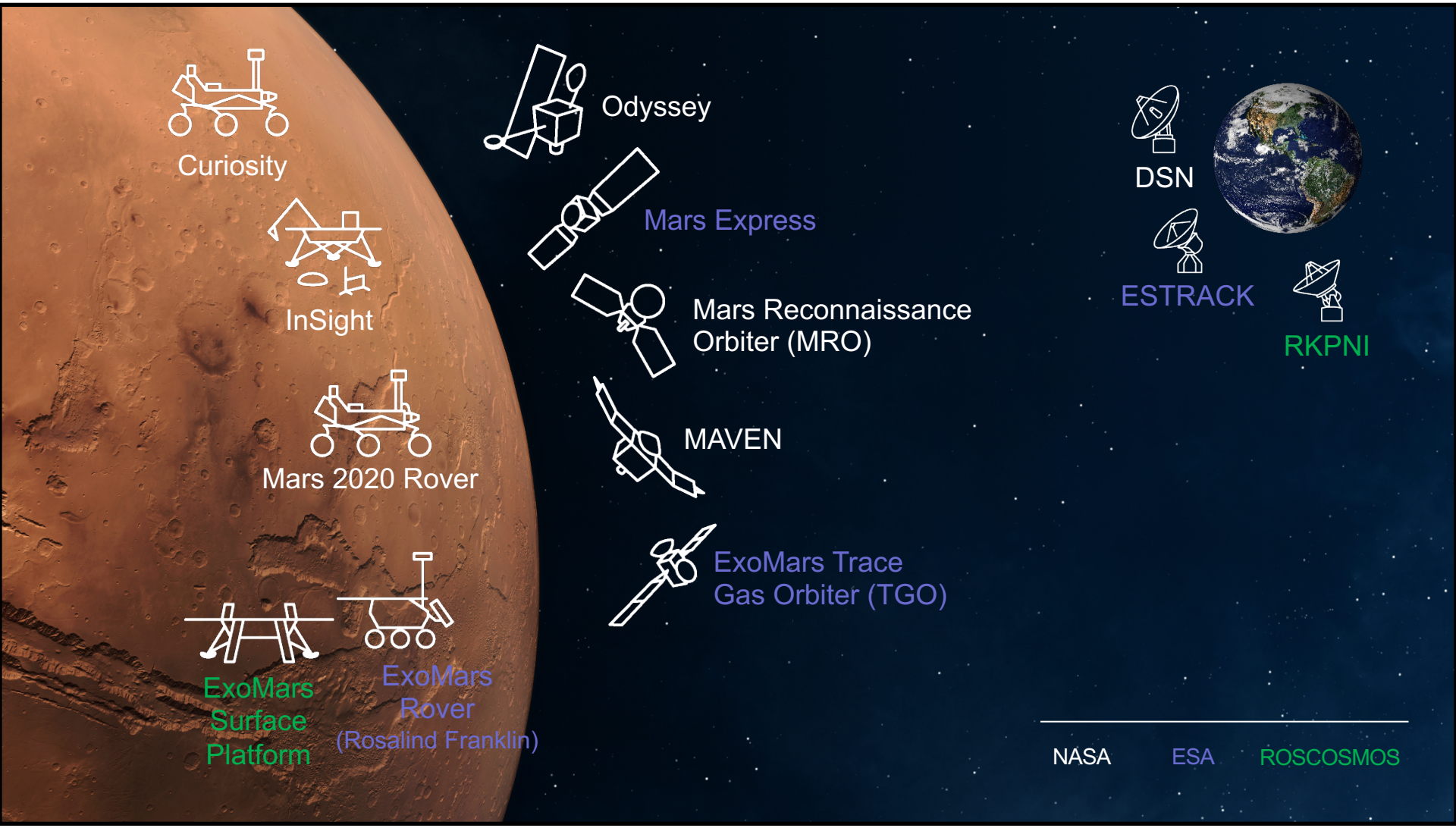


Topics

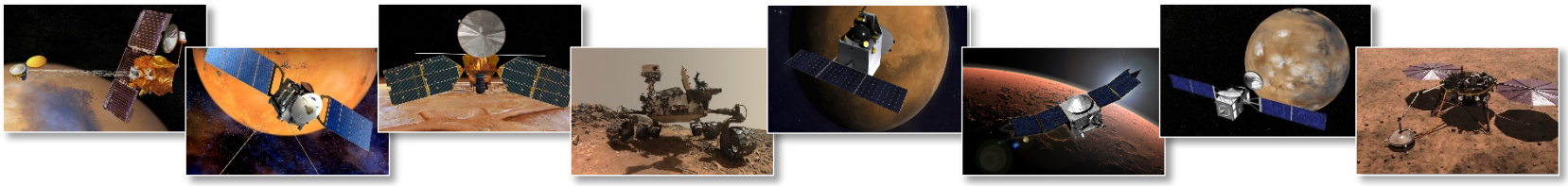
- The Mars Relay Network
  - Elements in the Mars Relay Network
  - Summary of All Operating Mars Missions
  - Summary of All Known Future Missions
- Inter-Spacecraft Communications
  - Frequency Selection Process
  - Relay Planning and Coordination
- Collision Avoidance
- The Known Future of NASA's Mars Program

The Mars Relay Network

Elements in the Mars Relay Network (2020)



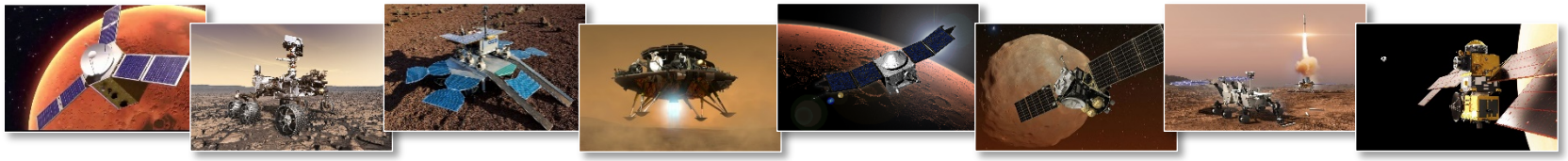
Operating Mars Missions



Launch Year	2001	2003	2005	2011	2013		2016	2018
Mission	Mars 2001 Odyssey	Mars Express	MRO	MSL (Curiosity)	MOM (Mangalyaan)	MAVEN	ExoMars TGO	InSight
Agency	NASA	ESA	NASA	NASA	ISRO	NASA	ESA	NASA
Type	orbiter	orbiter	orbiter	rover	orbiter	orbiter	orbiter	lander
UHF Radio (Max Rate)	CE-505 (256 kbps)	Melacom (128 kbps)	Electra (2048 kbps)	Electra-Lite (2048 kbps)	(none)	Electra (2048 kbps)	Electra (2048 kbps)	CE-505 (256 kbps)
Orbit/Site	385 km x 450 km 93 deg incl	300 km x 10,000 km 86 deg incl	250 km x 320 km 93 deg incl	Gale Crater 4.6 S 137.4 E	420 km x 77,000 km 150 deg incl	~180 km x 4500 km 75 deg incl	400 km x 400 km 74 deg incl	Elysium Planitia 4.5024 N 135.6234 E
Launch	7 Apr 2001	2 Jun 2003	12 Dec 2005	26 Nov 2011	5 Nov 2013	18 Nov 2013	14 Mar 2016	5 May 2018
Mars Arrival	24 Oct 2001	25 Dec 2003	10 Mar 2006	6 Aug 2012	24 Sep 2014	22 Sep 2014	19 Oct 2016	26 Nov 2018
Start of Prime Mission	19 Feb 2002	Nov 2004	7 Nov 2006	Aug 2012	Oct 2014	8 Nov 2014	Jun 2018	Jan 2019
End of Prime Mission	24 Aug 2004	Nov 2005	7 Nov 2008	Jun 2014	Apr 2015	8 Nov 2015	Dec 2022	Dec 2020
End Extended Mission	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	ongoing	pending

Missions in gray are not capable of relay.

Known Future Mars Missions



Launch Year	2020				2022	2024	2026	
Mission	EMM (Hope)	M2020	ExoMars 2020	HX-1 (Huoxing 1)	MOM-2 (Mangalyaan 2)	MMX	MSR Lander*	MSR Orbiter*
Agency	UAE	NASA	ESA	CNSA	ISRO	JAXA	NASA/ESA	ESA/NASA
Type	orbiter	rover	rover/lander	orbiter/ rover	orbiter	sample return	lander, rover	sample return
UHF Radio (Max Rate)	(none)	Electra-Lite (2048 kbps)	Qinetiq (1024 kbps)	TBD	(none)	(none)	TBD	TBD
Orbit/Site	20,000 km x 43,000 km 25 deg incl	Jezero Crater 18.4663 N 77.4298 E	Oxia Planum 18.159 N 335.666 E	265 km x 11,900 km TBD incl / site TBD	200 km x 2,000 km	Phobos	Jezero Crater 18.4663 N 77.4298 E	variable
Launch	14 Jul 2020- 3 Aug 2020	17 Jul 2020- 15 Aug 2020	26 Jul 2020- 11 Aug 2020	Jul/Aug 2020	2021-2022	Sep 2024	Jun 2026	Sep 2026
Mars Arrival	9 Feb 2021	18 Feb 2021	19 Mar 2021	Mar 2021	TBD	Aug 2025	Aug 2028	Sep 2027
Start of Prime Mission	25 Apr 2021	Mar 2021	Apr 2021	Mar 2021	TBD	Mar 2025	Aug 2028	Nov 2028
End of Prime Mission	13 Mar 2023	May 2023	Jan 2022	May 2023	TBD	Depart Aug 2028, @ Earth Jul 2029	Mar 2029	Depart Sep 2029, @ Earth Sep 2031

* Potential missions, not yet confirmed.

Missions in gray are not capable of relay.

Pre-Decisional Information – For Planning and Discussion Purposes Only

Inter-Spacecraft Communications

Proximity-Link Relay Services

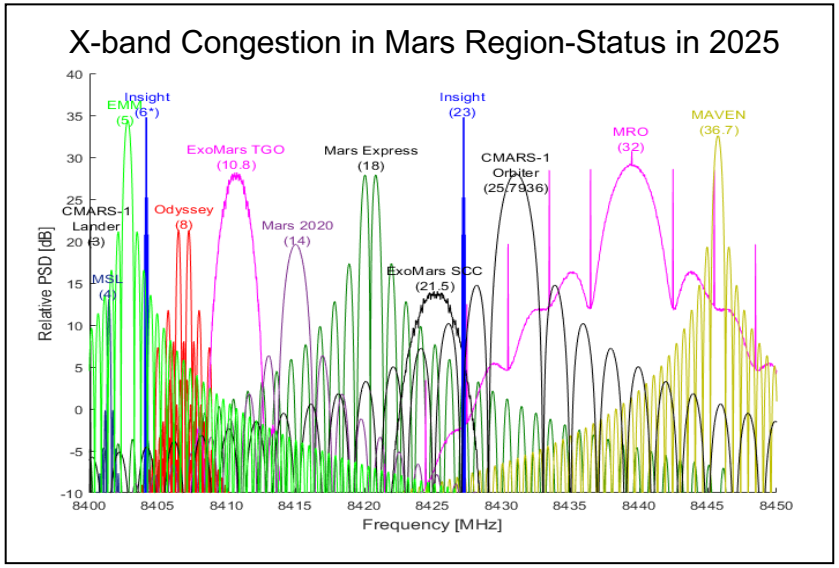
- Relay services in the Mars Relay Network are provided on the proximity link using CCSDS's Proximity-1 Protocol:
  - Channel 0 is always used as the hailing channel for all spacecraft.
    - *This is fixed in the implementation and can't be modified.*
  - Channels 0 and 2 are regularly used as the working channels.
- HX-1 will also use UHF frequencies to communicate between the orbiter and the rover:
  - From Tan Wei (tanwei@bittt.cn) on 15 Nov 2019:
    - "… the Proximity link radio equipment of CMARS supports multiple channels which have capability to use Channel 0, 1, 2, and 3. Due to consider ESA and NASA's current Mar's missions, CMARS adjust the priority order of channels which could be used. For the time being, CMARS will use channel 1 as hailing channel, then switch to the working channel after the link was established. Channel 2 and 3 will be used as primary working channels, and Channel 0 will be used as the backup of working channels if the primary working channel cannot be used in some cases …"
    - Channel 1: 404.4 MHz on the return-link and 435.6 MHz on the forward-link.
    - Channel 3: 393.9 MHz on the return-link and 444.6 MHz on the forward-link.
- ***It is requested that HX-1 avoid using Channel 2.***

Channel Number	Return-Link Frequency (MHz)	Forward-Link Frequency (MHz)
0	401.585625	437.1
1	404.4	435.6
2	397.5	439.2
2*	391	437.1
3	393.9	444.6

*** As implemented on MRO, MAVEN, and ExoMars TGO**

Background on Frequency Spectrum Regulations

- Use of the radio spectrum is governed by rules and regulations established by national and international organizations:
  - The International Telecommunication Union (ITU):
    - Makes spectrum allocations for all telecom services internationally.
    - Allocations are made by the consensus or vote of all UN administrations at World Radio Conferences (WRC) held every 3-4 years.
    - ITU Publishes a revised Radio Regulations after each WRC.
  - The Space Frequency Coordination Group:
    - Is an international organization focusing on frequency management Issues encountered by member space agencies (such as ESA, JAXA, CNSA, NASA, etc…), including frequency coordination, efficient use of the spectrum, and interference avoidance/mitigation.
    - The principal result of SFCG meetings is the adoption of resolutions and recommendations which express technical and administrative agreements.
    - A SFCG administrative resolution has asked member agencies to use assistance from JPL for selection of all deep space missions, including Mars missions.
      - Based on this resolution, JPL has selected the frequencies for all deep space missions operated by SFCG members.



Adapted from Farzin Manshadi

Deep Space Missions Frequency Selection Process

- Missions contact the JPL Spectrum Manager (currently Farzin.Manshadi@jpl.nasa.gov) as early as possible in their initial design phase, and must provide:
  - Trajectory data for the entire mission, typically by providing a file in SPK format, a standard trajectory file format used for most deep-space missions.
  - Telecom parameters that define the transmitter and receiver parameters and the spectral characteristics of the uplink and downlink signals for all major telecom modes.
  - Critical mission event descriptions to help avoid selecting channels that would result in potential interference during these critical mission events:
    - An interference free channel cannot always be found, but emphasis is placed on identifying channels with minimum interference during critical mission events.
- The JPL Spectrum Management Program conducts a channel selection study to select the appropriate frequency channel (or channels) compatible with existing channel assignments and applicable spectrum utilization policies/standards, including SFCG recommendations.
- The JPL Spectrum Manager provides a preliminary frequency selection report to the missions for approval.
- If approved, a full frequency selection report will be send to the mission.

Adapted from Farzin Manshadi

Ground Processes for Relay Coordination

MAROS + JPL

RELAY COMMUNICATIONS PLANNING

Mars Relay Operations Service

Provides the core capabilities that enable planning and coordinating UHF relay communications at Mars in a centralized and standardized manner

01 Strategic Planning

Define planning periods and the geometric visibility periods during which a UHF relay session can occur; and Orbiter and Lander teams negotiate initial relay support via MaROS

02 Tactical Planning

Any changes to the relay plan after command products are generated is a “tactical change” and is negotiated via MaROS

03 Forward-Link Commanding

Command or data products to be forwarded from Earth to the surface of Mars are transferred via MaROS

04 Return-Link Dataflow

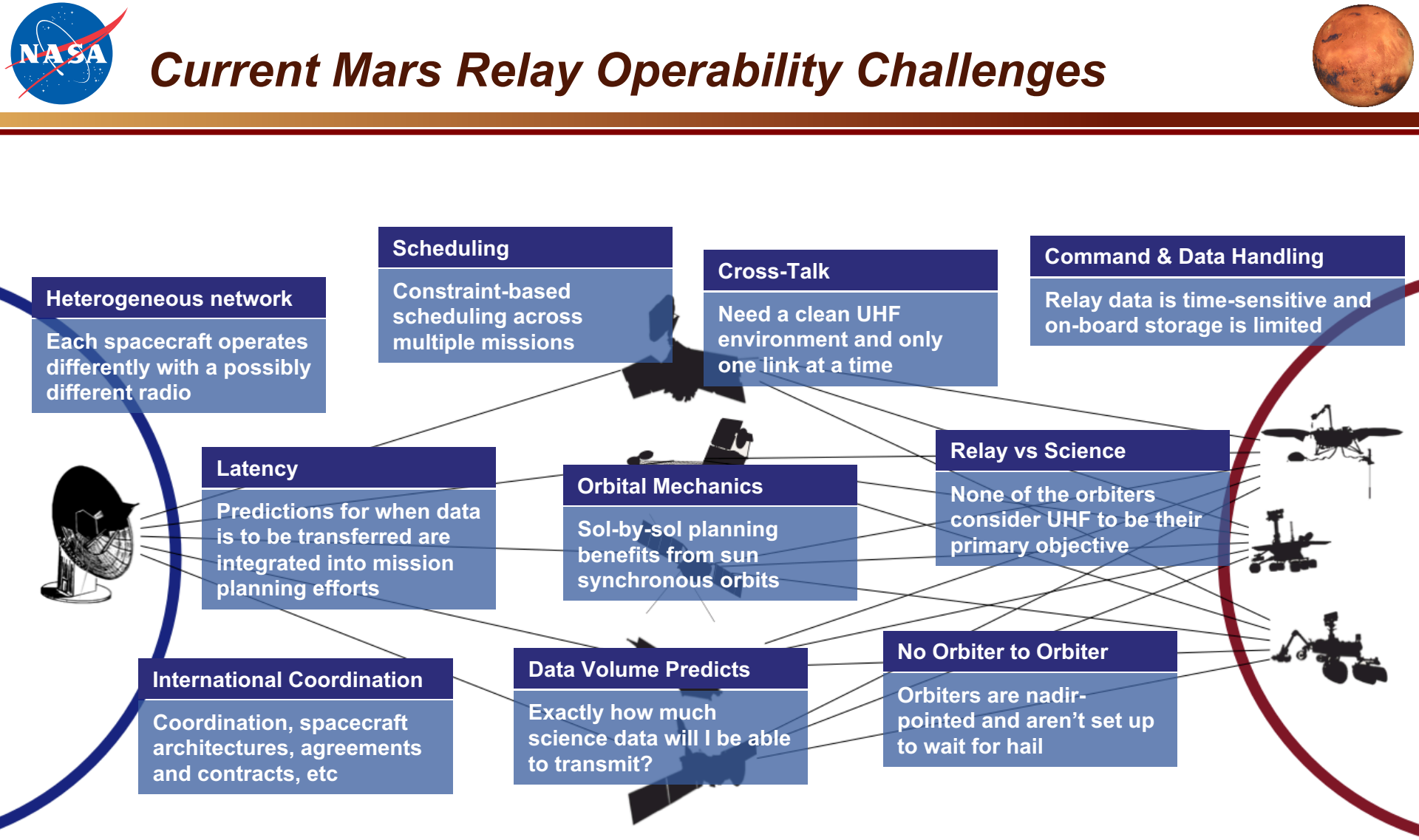
Predicting and tracking the return of data products from Mars to Earth is done via MaROS

05 Performance Monitoring

Relay performance reports are provided to MaROS for the purposes of assessing, monitoring, and trending the overall health of UHF relay links at Mars

Adapted from Jared Call

Current Mars Relay Operability Challenges



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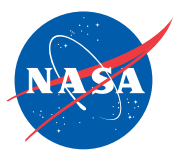
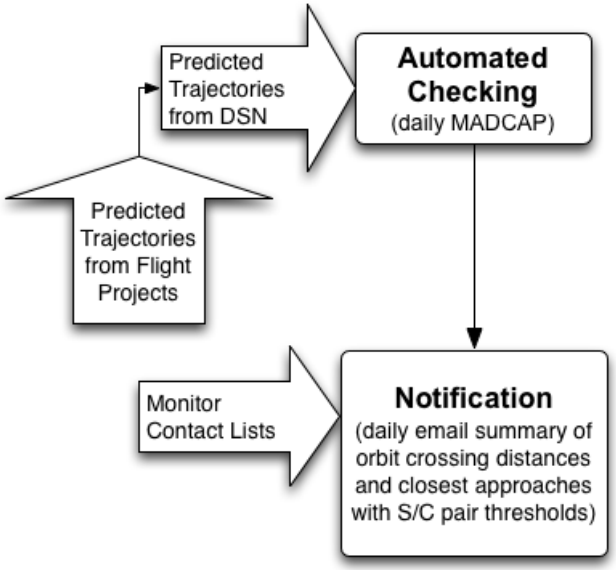
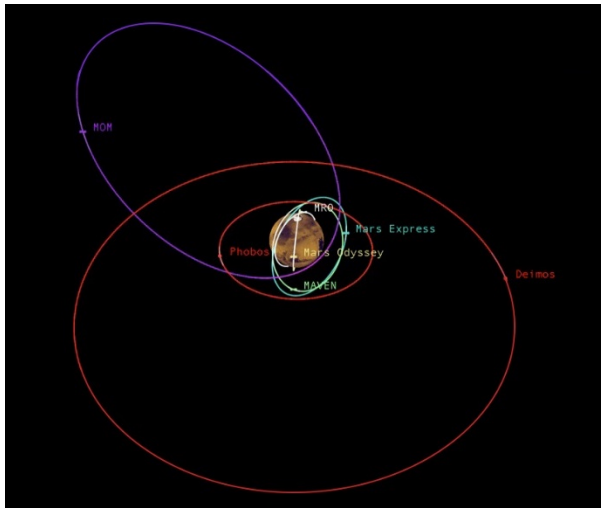


Collision Avoidance

Conjunction Assessment Process

- The Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) is currently used at the Jet Propulsion Laboratory on behalf of NASA to perform conjunction assessment at Mars and the Moon:
  - MADCAP performs pairwise comparisons of the ephemerides of the spacecraft included in the analysis.
  - Minimum relative distances for each of Close Approach Distance, Orbit Crossing Distance, and Orbit Crossing Time are each considered "Close Approach Events".
  - Times of the events and various orbit attributes are emailed to designated recipients.
  - All active Mars orbiters are currently included in the analysis, as are Phobos and Deimos, and reference orbits for the defunct Viking 1 and Mars Global Surveyor.
- ***It is desired to include HX-1 in this analysis.***





Adapted from David Berry

The Known Future of NASA's Mars Program

Priorities

- NASA's Mars Exploration Program is focused on safely delivering the Mars 2020 Rover to the surface of Mars.
- The proposed follow-on Mars Sample Return campaign, with first launch as early as 2026, would be the primary focus of the Program thereafter:
  - The Mars Relay Network is expected to operate through 2030, in anticipation of potential support to the Mars Sample Return missions.
- Other NASA or U.S. missions besides those indicated herein remain a possibility during the next decade, but these are speculative.

Thank You!